6. QUANTIFYING RESERVE SCENARIOS *(4)*

Resources required to quantify Reserve scenarios (using the BBM)

IFR coordinator (All levels)
Instream specialists (All levels)
Hydraulician (All levels)
Hydrologist (All levels)
Fluvial Geomorphologist (IERM & CERM)
Habitat integrity specialist (IERM & CERM)
Riparian vegetation specialist (IERM & CERM)

Approximate time required

Preparation : RERM III: 1 day per instream specialist
IERM : 1 day for instream and high flow specialists, 3 days for habitat integrity specialist, 6 days for hydraulician, 3 days for hydrologist, 4 days for coordinator
CERM : 5 days for instream, high flow specialists and habitat integrity specialist, 15 days for hydraulician, 5 days for hydrologist, 15 days for coordinator.

Specialist meeting : RERM III: 1 day for coordinator, instream specialist, hydraulician.
IERM : 2.5 days for all
CERM : 4 days for all

Technical Reporting : RERM III: 3 days
IERM : 5 days
CERM : 7 days

6.1 REVIEW OF INTERNATIONAL ENVIRONMENTAL FLOW REQUIREMENT METHODS

This review was undertaken by Ms Rebecca Tharme for DWAF as part of the Water Law Review as a report for policy development. The section below is an abstract of the report: Review of International methodologies for the quantification of the instream flow requirements of rivers (ref). As this report was tabled during November 1996, new developments since 1996 will invalidate some of the statements. Comments regarding this are made in *italics* and in brackets.

6.1.1 Background to instream flow assessments

Worldwide recognition of the need to establish the extent to which the flow regime of a river can be altered from the natural condition while still maintaining the integrity or an acceptable level of degradation of the riverine ecosystem, resulted in the establishment of the concept of instream requirements of rivers. Such requirements are calculated by means of an instream flow assessment, the essence of which is to ascertain the amount of water that must be left in regulated river systems to maintain the aquatic resources at some designated desirable level. The science of instream flow assessment originated in the western U.S.A, in the 1950s. In some other countries, assessment of the instream flow requirements of rivers only began to gain ground in the 1980s. For other parts of the world, there appears to be virtually no published mainstream literature that deals specifically with instream flows, suggesting that many have either not yet recognised the critical importance of instream flow assessments in the long-term maintenance and sustainability of freshwater systems, or made such assessments a priority.

There are a vast number of different instream flow methodologies worldwide, which have been used for assessing instream flows for a variety of aquatic species, activities and components of the riverine ecosystem. Commonly used methodologies generally fall into four main categories: historical flow record methodologies; hydraulic rating methodologies; habitat rating methodologies; and holistic methodologies.

6.1.2 Methodologies based on historical flow records

The first category of instream flow methodologies comprises those based on hydrological data, where fixed quantities of flow calculated from historical flow records are used as instream flow recommendations. The most common of these methodologies, the Montana Method, has remained virtually unmodified since its development in the 1970s, yet remains the second most applied method in North America and probably the world, after the Instream Flow Incremental Methodology (IFIM). It provides base flows as percentages of average annual flow, typically on a seasonal basis, for attaining various categories of general river condition. Another type of approach that is commonly applied is Flow Duration Curve Analysis, which uses specific percentiles from flow duration curves as recommendations for specific activities, or to provide month-by-month minimum flows.

Such methodologies are best used at the desktop reconnaissance level, to provide simple yet low-resolution estimates of quantities of river planning purposes. They are likely to be less useful than habitat-discharge type approaches, when negotiation or legislation of instream flow recommendations is required. Although such approaches are rapid, easy to apply, and require relatively little data, there is the risk that the single figures that constitute their output will routinely be applied, without sufficient understanding of their ecological relevance. Also, these methodologies do not address the dynamic nature of flow regimes, such as flow variability or specific flow events.

6.1.3 Habitat-discharge methodologies

The second and third categories of methodologies rely on the development of various relationships between habitat and discharge, to produce instream flow recommendations, and are termed hydraulic rating and habitat rating methodologies. Commonly, they focus on one or a few activities for which instream habitat can be predicted for target fish species, such as rearing and maintenance flows. They are sufficiently flexible to be applied for many species and activities, but cannot readily be used for certain components of the riverine ecosystem, such as riparian vegetation.

Hydraulic rating methodologies are single cross-section methodologies that rely on a single hydraulic parameter, such as maximum depth or wetted perimeter, as a surrogate for habitat factors limiting riverine biota, to develop a relationship between habitat and discharge.

These methodologies enable a fairly rapid, though simple, assessment of flows for the maintenance of habitat areas for requirements such as invertebrate production. They rely on the basic assumption that the single hydraulic variable can adequately represent the instream flow requirements of a target species for a particular activity, and placement of the single cross-section is critical to the results obtained. The most commonly applied hydraulic rating methodology worldwide and the third-most used one in North America, is a general one that uses the relationship derived from changes in river wetted perimeter with changes in discharge, as a basis for instream flow recommendation; for instance, Colling's Wetted Perimeter Method.

Habitat rating methodologies are the most commonly applied habitat-discharge methodologies. They use one or more hydraulic variables, usually depth and velocity, recorded at multiple cross-sections (Multiple Transect Analysis), in conjunction with criteria in quantities of suitable instream habitat with discharge. They generally produce more detailed information on the instream flow requirements of species than hydraulic rating approaches, as they use hydraulic data collected at a number of transects and relate it to species-specific physical habitat requirements. However, they are also strongly reliant on the location and number of transects, as well as on the adequacy of available knowledge on the habitat requirements of the species of concern.

6.1.4 The Instream Flow Incremental Methodology (IFIM)

IFIM evolved from earlier habitat rating methodologies and represents the state-of-the-art in terms of habitat-discharge methodologies. It is currently considered the most sophisticated, and scientifically and legally defensible methodology available for quantitatively assessing the instream flow requirements of rivers and is, therefore, the most commonly used instream flow methodology worldwide. It is widely used in the U.S.A., and has more recently been applied in Australia, New Zealand, Britain and South Africa. It comprises a set of analytical procedures and computer models, including its best known component, the Physical Habitat Simulation Model, PHABSIM II. In its entirety, it is used to evaluate the effects of incremental changes in instream flow on channel structure, water quality, temperature and availability of suitable physical habitat for selected target aquatic species. It has been routinely applied to assess instream flows for fish and invertebrates, and has more recently been adapted to recommend flows for flushing, wildlife, maintenance of water quality, habitat under peaking hydropower operation, and riparian vegetation. The appropriateness of IFIM for these more recent types of application has yet to be assessed.

Aspects of the assumptions, logic and content of IFIM have been criticised by a number of authors, highlighting common areas of concern, limitations, and problems with its procedures. However, the vast body of criticisms of IFIM is partly an indication of the considerable attention it has received and its numerous applications, and not necessarily of its inherent weaknesses. Several types of river and hydrological regime have also been identified for which IFIM is difficult, or inappropriate to use in its current form, and a few comparisons with other instream flow methodologies have been made. IFIM requires intensive verification, and has potential for misuse if applied by inexperienced users.

6.1.5 River Hydraulics and Habitat Simulation Program

RHYHABSIM is a simplified version of the PHABSIM II component of IFIM. It possesses similar, though somewhat reduced, scope for application to IFIM, has similar data requirements, and comprises the same kind of procedures. It is considered to have potential for future application and development.

6.1.6 Holistic Methodologies

An holistic ecosystems approach to the assessment of instream flows, in which all components or attributes of the ecosystem and their interrelationships are addressed, is considered by some ecologists to be the future direction of development of instream flow methodologies.

The final main category of methodologies are holistic ones, such as the Building Block Methodology (BBM), Holistic Approach and Expert Panel Assessment Method; all of which have been developed in the last decade. As these methodologies are very recent, there are few applications of them other than in their place of origin, and only local critiques are provided. Moreover, they require formal guidelines, comparison with other international approaches, testing and verification of their assumptions, and assessments of their reproducibility. The most clearly documented and well-structured methodology is the BBM, for which a manual is available (King et al., 2000). Presently, it is the most commonly used instream flow methodology in South Africa, and was also recently applied overseas for the first time in Australia.

The Australian-based Holistic Approach, closely resembles the BBM, but there is insufficient documentation of it for all the differences between the two methodologies to be apparent. The Expert Panel Assessment Method has been applied in Australia, but there is, as yet, no explicit guide to its procedures.

Holistic methodologies exhibit several advantages over other types of methodology, in that they are pragmatic, robust and designed to cope with instream flow assessment in situation where time, finances, available data and expertise are constraints. They can potentially be used to address all components of the riverine ecosystem, and have clear strong links with the natural hydrological regime. They also consider all aspects of flow regime, such as the magnitude and timing of both base flow and flood events, and their outputs can be generated at several levels of resolution. However, they rely to a considerable extent on professional judgement, so care must be taken to apply them in a rigorous, well-constructed manner, in order to ensure sufficiently reproducible results.

6.1.7 Alternative approaches to instream flow assessment

Several alternative approaches to instream flow assessment exist, such as Multiattribute Tradeoff Analysis; the Habitat Quality Index Method; and Energy Analysis. However, these are poorly described, tend to be fairly case-specific, or are of limited broader application.

6.1.8 Hydraulic simulation models

Many instream flow methodologies rely on hydraulic variables as critical inputs. This requires either extensive field measurements of habitat characteristics over a wide range of discharges, of where data are limited or unavailable, hydraulic modelling. Hydraulic models are usually applied for this purpose rather than as instream flow approaches *per se*, although they are occasionally used in conjunction with professional judgement to recommend instream flows.

There are several types of hydraulic model, the most common of which are routinely applied in PHABSIM II. All of these models have a variety of data requirements, assumptions, advantages and limitations, and should be selected and used under the guidance of an experienced hydraulic modeller.

Major advancements in the field of hydraulic modelling have been made in recent years, in response to the difficulties experienced in applying standard hydraulic models to rivers. There is potential for the future development of more sophisticated hydraulic models for simulation of instream conditions, such as the development of two-dimensional models. As hydraulic modelling is a critically important component of the majority of the more sophisticated habitat-discharge methodologies, and of some holistic methodologies like the BBM, research should be directed at advancing the state-of-the-art, and at training hydraulic modellers and ecologists in this field.

6.1.9 Methodologies for assessing flushing flow requirements

There is no standard methodology for routine prescription of flushing flows, and many uncertainties are associated with existing approaches. Methodologies need to be adapted to the specific needs and characteristics of each study. Probably one of the best approaches is to use an office technique that produces the most conservative flow estimate of several ones, and to refine this initial estimate using field techniques, such as empirical assessments of bed transport under a series of flow releases. Currently, many flushing flow recommendations are largely made on the basis of professional judgement, and follow-up or verification studies are generally not undertaken. A number of alternative methodologies exist for the establishment of flushing flow recommendations, which can be separated into three broad categories: hydrologic event methods; channel morphology methods; and sediment transport mechanics methods. The latter category includes the majority of available methodologies. No single methodology entirely addresses magnitude, duration, effectiveness, timing and frequency of flushing.

6.1.10 Methodologies for assessing instream flows for riparian vegetation

There is a notable absence of formal methodologies for addressing instream flow requirements of riparian vegetation and historically, the flow needs of the riparian ecosystem itself have probably been underestimated. Prior to the 1980's, there was little emphasis on the development of this particular field of instream flow assessment, and existing methodologies have evolved rapidly over the past decade.

Currently, there are three major, often patly integrated, ways in which instream flow requirements for riparian vegetation are assessed. The first entails the linkage of stream discharge associated hydrological variables with variables associated more directly with the riparian belt, particularly the riparian water table; an indirect link is then sometimes established between the latter variables and the vegetation. Flow-vegetation growth models represents the basis of a second set of techniques, and the third approach is the BBM.

Considerable research is required to improve the level of understanding of relationships between riparian vegetation and instream flow, if successful methodologies are to be developed, particularly for routine application. Such methodologies will need to consider multi-species responses and several aspects of the flow regime, when determining the instream flow requirements of entire riparian communities.

6.1.11 Methodologies for assessing instream flow requirements for wildlife

The field of instream flow methodologies for wildlife has been much neglected, relative to the development of methodologies for other purposes, and information on this topic is scarce. To date, applications of methodologies providing instream flows for wildlife have been few worldwide, most are conceptual or in their formative stages, and there is considerable potential for advancement in this field. There are no reviews of this topic, and information is scarce.

Holistic methodologies, particularly the BBM, have potential for the inclusion of wildlife as an integral component of the riverine ecosystem, and this should be further explored.

6.1.12 Methodologies for water quality purposes

The majority of instream flow methodologies to date have focussed entirely on flow quantity, and water quality has often been disregarded, this despite its obvious importance.

6.1.13 General comments on instream flow methodologies

The majority of instream flow methodologies are poorly documented in the mainstream scientific literature, probably because many of them were developed and applied in an ad hoc fashion, by various agencies, in response to case-specific instream flow problems, and have not been updated in recent years. Many of them do not have clearly documented, stepwise procedures for their application, or manuals. The development of instream flow methodologies has been heavily biased towards assessment of the flow requirements of single fish species, yet many of these methodologies could be modified for assessing flows for other biota or ecosystem components.

Generally, existing methodologies produce one or two outputs: a recommended minimum discharge value; or a continuous function, such as suitable habitat versus discharge. The latter is a more useful result, but the point of inflection for curves based on such relationships may be difficult to identify, requiring professional judgement.

Many instream flow methodologies may not be applicable for rivers outside the ones on which they were developed, so they needed to be rigorously tested with regards their degree of transferability, and all of their main assumptions should be considered. Several of them may also require updating, to include useful advancements, e.g. in the fields of hydraulic and hydrological modelling. Few methodologies consider the requirements of more than a few species, life stages, or ecosystem components; only holistic methodologies address this shortcoming. Most of the methodologies were developed for rivers and stream, so few are likely to be applicable for non-flowing aquatic systems, such as wetlands and lakes.

Most approaches assume that the river is morphologically stable, yet significant changes in morphology are likely with river regulation. This is an important consideration, particularly in the case of habitat-discharge methodologies.

The majority of historical flow record methodologies and habitat-discharge methodologies have remained unmodified in recent years. It has been emphasised that future efforts should be focussed on improving the information base of such methodologies, rather than on their further development. Habitat rating methodologies provide more scope than hydraulic rating approaches, but also have limitations to their use, and should be applied for a number of species and/or activities, unless all limiting factors are known. Transect-based approaches are more suitable for rapid assessments, while mapping techniques are better suited to more intensive fields studies, and have the potential to produce the highest resolution results.

Expert judgement is needed for all available methodologies. Despite the wide use of a number of methodologies worldwide, none of them have been adequately evaluated. There is also a general lack of ecological knowledge on the instream flow needs of riverine biota and ecosystem components, which limits the application of all instream flow methodologies. Field studies and experimental releases are required for validation of instream flow recommendations, and such biological validation of existing methodologies, rather than the development of new ones, has been emphasised.

6.1.14 International application of instream flow methodologies and future advancements

Internationally, most of the effort made in developing and applying instream flow methodologies, has been in North America. South Africa, Australia, New Zealand, Norway, and Britain have more recently begun to apply available approaches and, in some instances, to develop more appropriate methodologies for local conditions. Although North America has historically been at the forefront of the field of instream flow assessment, many of the methodologies developed there have limited application elsewhere. The selection of a particular methodology in North America is documented as being based on the following criteria; the nature of the problem; time financial and logistical constraints; and the reliability and legal acceptability of the methodology.

Considerable emphasis has been placed on instream flow legislation in North America. However, there has been little effort in this regard elsewhere in the world, and for many countries the status of instream flow methodologies and associated legislation cannot be ascertained. South Africa is now probably the country with the most detailed legislation relating to instream flow requirements.

Major research needs for instream flows were identified in North America, as follows: additional species habitat information and preference curves; techniques for assessing instream flows for atypical conditions; testing of fish habitat flow production relationships, and assessment of the potential biological consequences of flows recommended to maintain instream habitat.

6.1.15 Application of instream flow methodologies in South Africa

Selection of an appropriate instream flow methodology or methodologies for application in South Africa will be primarily limited by the availability of data on the river system of concern, and on time, financial and manpower constraints. For this reason, a hierarchy of methodologies would probably be most appropriate, with professional judgements being exercised at all levels. *(This has been developed as can be seen in this document)* The broadest level of the hierarchy should comprise reconnaissance-level assessments of instream flow needs. Historical flow record approaches that are likely to be most useful at this level include the Montana Method, FDC Analysis and Bulk Water Estimate Method. However, all of these methods require rigorous testing and comparison with other approaches, and the Montana Method should be applied with caution for rivers with different flow regimes and channel morphologies from the ones on which it was developed. *(The RERM has been developed after evaluating the mentioned approaches)*

The BBM has been specifically developed for local conditions, and seems to be the most appropriate methodology at present, for routine application at an intermediate level. It would be useful to include more formal modelling of hydraulic or various habitat discharge relationships within this methodology. *(This has been undertaken and is included)* At the final level of the hierarchy, with rivers of high conservation priority, it might be appropriate to apply either IFIM or RHYHABSIM. However, IFIM is highly complex, and users would required updated formal training and guidance for applications of it to be successful. RHYHABSIM has not been applied locally, this despite evidence that it may have considerable potential for future application with further modification, and either independently or within holistic methodologies like the Holistic Approach.

In an assessment of the degree to which IFIM could be applied in South Africa, it was concluded that the methodology cannot provide a complete instream flow assessment, in the way needed locally most of the time. DWAF requires detailed recommendations of the modified flow regime that should be released from a dam for the maintenance of a river in some predetermined state. This extends beyond the traditional PHABSIM II outputs, which describe losses and gains in physical habitat with changes in discharge for chosen species, without a comprehensive link to the natural hydrology of the river. IFIM has been designed for management at the species level, whereas South African requires a methodology for facilitating the management of river flow at the ecosystem level.

In terms of the application of instream flow for South African rivers, none of the historical flow record, hydraulic-rating or habitat-rating methodologies reviewed in this report have been applied and tested for local conditions, apart from IFIM. It would be worthwhile to test the degree of applicability for local conditions of at least the most commonly applied methodologies in each of these categories. Flexible application of a suite of methods or aspects of methodologies, identified according to eh case at hand, might prove to be one of the more appropriate ways of assessing instream flows in future.

Realistically, it is likely that the selection of a particular methodology will be case-specific, and defendant on available data, time, finances and expertise.

6.2 BUILDING BLOCK METHODOLOGY

At this stage this is the best documented (King et al, 2000) and therefore recommended approach to determine the IFRs. The focus of this document is therefore the BBM and this approach will be described in detail in this report. The specialist appendices forming part of this document as well as the previous RDM documents are prepared for the BBM. It must be noted however that the specialist appendices which refer to preparatory work for the BBM are also applicable for the DRIFT and F-SR response.

6.2.1 Introduction (King and Louw, 1998)

The issue of instream flow requirements for river maintenance was first addressed nationally in 1987, through two major workshops (Ferrar, 1989; Bruwer, 1991). At that time, DWAF policy was shifting from one of the provision of water in response to demand, to one of holistic management of the nation's water resources. This policy shift was reflected in documents explaining established and new thinking on water quality management (DWAF, 1991), on water for the environment (DWAF, 1992), and on managing low flows to address water quality problems and for the benefit of rural, developing communities and riverine ecosystems (Water Research Commission, 1993). The White Paper on Water Supply and Sanitation Policy (DWAF, 1994) outlined a major dilemma facing modern South Africa. There was recognition that the riverine environment is not a user of water in competition with other users but is the base of the resource itself, which needs to be actively cared for if development is to be sustainable. Inevitably, the urgent need to provide more water services will often be in conflict with the desire to maintain or improve the condition of the nation's rivers.

Scientific initiatives have paralleled evolving DWAF policy. Among these was an assessment by King & Tharme (1994) of the Instream Flow Incremental Methodology (IFIM) developed by the U.S. Fish and Wildlife Service (Stalnaker *et al.*, 1994); flow-related studies of two of the largest rivers flowing into the Kruger National Park (Chutter & Heath, 1993; O'Keeffe *et al.*, 1996; Weeks *et al.,* 1996), and the launch of the Kruger National Park Rivers Research Programme.

With growing experience, a need was recognised for a practical and rapid methodology for assessing instream flow requirements. King & Tharme (1994) had concluded that IFIM could not provide a comprehensive answer on this requirement in the way needed in South

Africa. The traditional IFIM approach was hampered by the country's severe limitations in terms of data and time, and its use of target species seemed inadequate in a country where accent was on management of the complete instream and riparian components of river ecosystems rather than of important aquatic species. IFIM's routine output falls short of being a comprehensive description of a recommended modified flow regime, as was needed for whole-river management. There were also scientific concerns with IFIM, such as the way the output of its model, PHABSIM II, is interpreted and used (King & Tharme, 1994).

These conclusions and DWAF's urgent need to provide extensive extra water services led to the development of a local methodology that could rapidly inform on instream flow requirements. **Its basic concepts are simple. These are that some flows within the total flow regime of any river are more important than others for maintenance of that river ecosystem. These flows can be identified, and described in terms of their timing, duration and magnitude. Where a water-resource development is planned, the identified flows for the downstream river can be combined to define a recommended modified flow regime that is specific for the river. This information can be used as input at the planning stage of the development and, if the scheme proceeds, to guide design of an appropriate monitoring programme and eventual day-by-day flow management.**

Because of time constraints, it was recognised from the outset that the methodology would have to rely to a large extent on best available knowledge and expert opinion. The core of the methodology has thus become, for any one river, a workshop attended by senior river scientists representing specified fields of expertise. Such a workshop has been found to be the most successful way of gleaning information from the specialists, and of guiding them to a consensus decision. This decision takes the form of a recommended flow regime that it is felt should facilitate maintenance of the river in some pre-determined desired state. Water managers and engineering and social consultants linked to the proposed water development also participate in the workshop, contributing knowledge on hydrological, hydraulic and social aspects, and gaining knowledge on why particular flows are important from the perspective of river functioning. Around the core activity of the workshop has developed a structured process for compiling the specified workshop material and for using the workshop output in further phases of the development.

6.2.2 Background to and origin of BBM (King and Louw, 1998)

The BBM originated in two major South African workshops on instream flow assessments, where parts of it began evolving in the form of the "Cape Town" and "Skukuza" approaches (King & O'Keeffe, 1989; Bruwer, 1991). Parallel development by Australian colleagues led to a joint description of an approach (Arthington *et al.,* 1992), at that time termed "The Holistic Method". Further separate development took place in South Africa during applications of the methodology, which was recognised through its final South African name of the Building Block Methodology (BBM). These workshop applications, each designed to produce a rapid first estimate of the instream flow requirement for a river targeted for water-resource development, were mostly convened by the Environment Studies sub-directorate of DWAF, and involved many of the country's most experienced river scientists.

Between 1991 and 1996, BBM workshops were held for the following rivers: the Lephalala, Berg, Olifants (Western Cape), Olifants (Transvaal), Letaba, Luvuvhu, Lomati, Koekedouw, Senqu (Lesotho), Mooi, Tugela, Mvoti, Sabie, Bivane and Logan (Australia).

6.2.3 Assumptions and character of the BBM (King and Louw, 1998)

In the methodology the following assumptions are made.

The biota associated with a river can cope with those low-flow conditions that naturally occur in it often, and may be reliant on higher-flow conditions that naturally occur in it at certain times. This assumption reflects the thinking that the flows that are a normal characteristic of a specific river, no matter how extreme, variable or unpredictable they may be, are ones to which the riverine species characteristic of that river are adapted and on which they may be reliant. On the other hand, flows that are not characteristic of that river will constitute an atypical disturbance to the riverine ecosystem and could fundamentally change its character.

Identification of what are felt to be the most important components of the natural flow regime and their incorporation as part of the modified flow regime will facilitate maintenance of the natural biota and natural functioning of the river.

Certain kinds of flow influence channel geomorphology more than others. Identification of such flows and their incorporation into the modified flow regime will aid maintenance of the natural channel structure and diversity of physical biotopes.

In total, the flows incorporated into the modified flow regime will constitute the instream flow requirement (IFR) for the river. As the minimum acceptable value will have been entered for each flow component incorporated, the IFR describes, in space and time, the minimum amount of water that it is felt will facilitate maintenance of the river at some pre-defined desired state.

The recommended flows are identified and their magnitudes, timing and duration decided upon in the BBM workshop. Initially, thought is focused on the characteristic features of the natural flow regime of the river. The most important of these are usually: degree of perenniality; magnitude of base flows in the dry and wet season; magnitude, timing and duration of floods in the wet season; and small pulses of higher flow, or freshes, that occur in the drier months (Fig. 1). Attention is then given to which flow features are considered most important for maintaining or achieving the desired state of the river, and thus should not be eradicated during development of the river's water resources (Fig. 1). The described parts of each flow component are considered the building blocks that create the IFR, each being included because it is understood to perform a required ecological or geomorphological function (Fig. 2). The first building block, or low-flow component, defines the required perenniality or non-perenniality of the river, as well as the timing of wet and dry seasons. Subsequent building blocks add essential higher flows.

Fig 6.1 **Focusing though on (a) perceived important features of a river's natural flow regime and (b) which of these should be retained in an IFR**

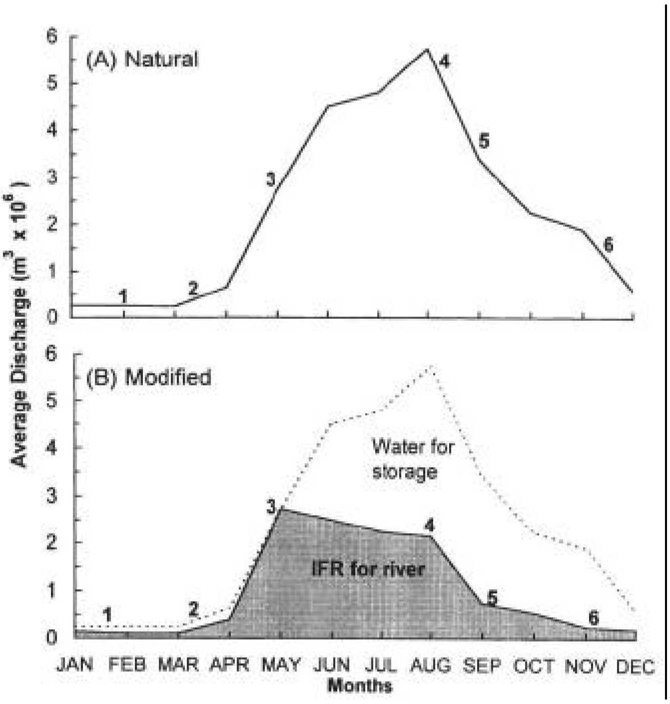
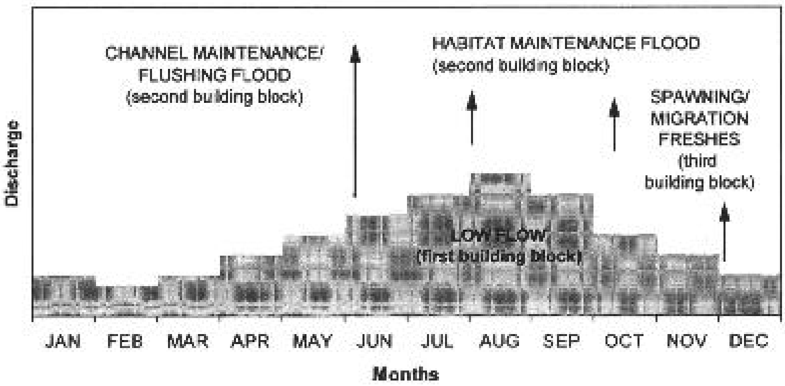


Fig 6.2 **An hypothetical IFR created using the building Block Methodology**



6.2.4 Step by step approach required for the application of the BBM

Preparatory work required for the application of the BBM

- Determine the study area
- Undertake the Habitat Integrity (R4, R5, BBM manual)
- Identify Resource units (chapter 4, this document, Appendix A, R2)
- Select IFR sites (chapter 4, this document; R 22, BBM manual)
- Undertake the preparatory hydrology work (R16)
- Undertake the required hydraulic work (R17)
- Undertake the required geomorphological work (R18)
- Undertake the required aquatic invertebrate work (R21)
- Undertake the required fish work (Appendix G)

- Undertake the required riparian vegetation work (R19)
- Determine the PES, EIS and recommend the ERC (chapter 5 this document)
- Define the ERCs (chapter 5 this document)
- Integrate and prepare all information into a specialist meeting starter document (BBM manual)

IFR Specialist meeting[1]

During the IFR specialist meeting, the Reserve scenarios are generated. The standard BBM approach is to supply in detail the Reserve scenario for the recommended ERC and then to extrapolate to other ERCs.

Flows are determined for maintenance flows (those flows that will maintain the system at the ERC during years other than drought years) and for drought periods (flows that will only allow for survival of the most critical components of the ecosystem) during the IFR specialist meeting. The method used during the IFR specialist meeting to determine maintenance flows are the same as that for drought flows. The process during the specialist meeting follows a defined set of procedures and is described below.

- The assurances of maintenance and drought flows are determined based on the hydrological characteristics of the system.
- The highest low flow (base flow) month and lowest low flow month on average are selected from the hydrological record. The observed daily hydrological record for the site itself, if available, or from a representative site could be used, or monthly data if daily data is not available.
- The low flow values specific to the IFR site are determined for these months and the flow rates are used as the upper and lower limits of the range of low flows.
- The low flows for the rest of the months are interpolated by following the shape of the natural annual hydrograph. This extrapolation is undertaken by the hydrologists and checked by the ecologists. The low flows are specified in cubic metres per second (m^3/s).
- Each river specialist describes the physical parameters (eg water level, velocity, depth) required with motivations. Some of the disciplines provide primary and some secondary motivations. Primary motivations are those provided by the disciplines where a lower flow rate than required cannot be accepted. Secondary motivations are those provided by disciplines that could maintain the component with less flows, but for which higher flows required for the other components will not be harmful.
- After each flow is agreed on, the flows are checked against the hydrological record. Normal or average hydrological years are utilised to check maintenance flows and the driest years to check drought flows.
- During the wet season high flow events are determined and motivated for. High flows refer to freshes, small, medium and large floods. A fresh is a relatively small increase in base flow. The high flows are specified in m^3/s where the specified flow refers to an instantaneous peak. As the hydrological data is provided in mean

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[1] Previously referred to as the IFR workshop. The term workshop however led to expectations of stakeholder participation etc, much rather than a specialist structured meeting, therefore the revised term IFR specialist meeting.

daily averages, the peaks recommended are converted to slightly lower flows to reflect the mean daily average. Fig 6.3 illustrates a blank IFR table which is filled in during the specialist meeting.

- The duration of the high flows is specified in days. The shape of the floods is based on the shape of the natural hydrograph. The specified peaks include the low (base) flows. When the total volume of each flood is calculated, it excludes the low flow volume which is already included in the total low flow volume.
- The high flow or high flows are specified in a specific month. However, all flows recommended are linked to a natural climatic trigger. Therefore, a flood will only be required if the hydrological record indicates that it would have occurred under natural circumstances.
- A hydrological check of each flood is repeated.
- These flows constitute the design IFRs which are then converted to the final IFR results.
- The IFR model or the Desktop Model links the drought and maintenance flows to a natural trigger in a historical time series. The IFR model (which is used when daily data is available) allows the specialists to view the sequence of occurrence in a historic time series indicating how often drought and maintenance flows occur. This calibration leads to the final IFR results being specified in a format suitable for linking with the Water Resources Yield Model (WRYM). If no daily data is available, the DSS is used to undertake a similar exercise, but based on monthly data. The final format is discussed in chapter 7 and 8.
- Extrapolation for other ERCs : As the Reserve approach is scenario based, a result for a specific river state is insufficient and IFRs for various river states must be supplied. The results determined for the recommended ERC are used to extrapolate to different classes using the Desktop Model. The results are then broken down to the hydraulic parameters and tested by specialists to determine whether it achieves those characteristics which define the, other than recommended, ERCs.
- All IFR results in the correct format are immediately made available to system modellers.

Reporting

A report which provides the required background information as well as documenting all the results and relevant motivations from the specialist meeting is produced. With this report, the IFR results are provided both in written and electronic format. The CD with the final report must also include the hydrology used to run the models so that results can if necessary be manipulated in future using the same hydrology.

Evaluation of operational scenarios

This process forms part of the BBM process but is described in chapter 8.

Fig 6.3 **Example of a completed IFR tables**

: DLIFR -> Drought Low Flows
: MHIFR -> Maintenance High Flows
: DHIFR -> Drought High Flows
: MHDur -> Event Duration for MHIFR
: DHDur -> Event Duration for DHIFR
: High flows (MHIFR & DHIFR) represent peaks less low flows.
: Where there are two or more high flow events, they are lumped together

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**TOTALS**	
MLIFR													**MCM**	**% of Nat MAR**
(m^3/s)	0.34	0.54	0.67	0.80	0.78	0.66	0.49	0.33	0.26	0.26	0.24	0.28		
(MCM)	0.91	1.40	1.78	2.13	1.90	1.77	1.27	0.87	0.67	0.70	0.64	0.73	14.775	11.30
Depth (Max) (m)	0.24	0.28	0.31	0.33	0.32	0.30	0.27	0.24	0.22	0.22	0.21	0.23		
Depth (Average) (m)	0.12	0.15	0.17	0.18	0.18	0.17	0.14	0.22	0.11	0.11	0.10	0.11		
Wetted perimeter (m)	12.3	13.6	14.7	15.1	14.9	14.7	13.3	12.3	11.8	11.8	11.6	12.1		
Velocity (m/s)	0.24	0.28	0.29	0.31	0.31	0.28	0.27	0.23	0.22	0.22	0.22	0.21		
MHIFR														
(m^3/s)	4.92	9.78	8.80	19.52	8.80	5.28								
(MCM)	0.60	1.18	1.06	3.04	1.06	0.64							7.579	5.80
(Days)	2.00	2.00	2.00	3.00	2.00	2.00								
Depth (Max) (m)	0.62	0.79	0.76	1.00	0.76	0.63								
Depth (Average) (m)	0.33	0.42	0.39	0.61	0.39	0.34								
Wetted perimeter (m)	23.00	29.90	29.50	31.30	*****	23.60								
Velocity (m/s)	0.67	0.83	0.80	1.09	0.80	0.70								
DLIFR														
(m^3/s)	0.13	0.23	0.29	0.35	0.34	0.28	0.20	0.13	0.10	0.10	0.09	0.11		
(MCM)	0.36	0.59	0.76	0.93	0.82	0.76	0.53	0.34	0.25	0.26	0.23	0.27	6.081	4.65
Depth (Max) (m)	0.17	0.21	0.23	0.24	0.24	0.23	0.20	0.17	0.15	0.16	0.15	0.16		
Depth (Average) (m)	0.07	0.10	0.11	0.12	0.12	0.11	0.09	0.07	0.06	0.06	0.06	0.06		
Wetted perimeter (m)	10.5	11.6	12.1	12.3	12.3	12.1	11.3	10.5	10.0	10.0	9.3	10.0		
Velocity (m/s)	0.20	0.21	0.22	0.24	0.24	0.21	0.20	0.20	0.18	0.18	0.19	0.19		

LONG TERM % OF THE MAR : 33.61%

6.3 ADDITIONAL DEVELOPMENTS

As the BBM and IFR quantification approaches were gradually incorporated into the methodology that was required to determine the Ecological Reserve for water quantity in rivers, it became apparent that there were several shortcomings that were not simple to address within the existing framework. One of these was the fact that the BBM focuses on a single river condition design (i.e. a single ERC) during the specialist meeting. It was found to be time-consuming and conceptually difficult to repeat the process for several categories. As an interim solution, the Desktop model (Appendix C) is often used for alternative categories after being ‘calibrated’ to match the results for the single category generated in the workshop.

The other major drawback was that the specialist knowledge of the river and the conceptual basis for the quantification of the flows was not adequately captured. The main consequence of this was that when it became necessary to evaluate additional flow regime scenarios, all of the specialists had to take part in the process. This frequently took place quite a long time after the main workshop and meant that the specialists had to spend time reviewing their information in preparation. The evaluation of different scenarios is now an integral part of the Reserve process and may be generated in response to stakeholder input, or as part of a water resource systems analysis where management constraints and other user requirements are accounted for.

It is now considered essential that the information needed at the scenario assessment stage should be generated at the quantification workshop. The scenario assessment process should then only require a limited number (one or two) of key specialists to interpret the information in a way that allows the ecological impacts of different scenarios to be quantified.

One of the considerations in developing new, or modified, approaches was that the hydrological output should be in the same form as that which has been generated by the BBM. It has become accepted that one of the outputs should be in the form of a table of flows for each month of the year for different levels of assurance. This type of information is compatible with the way in which the WRYM accounts for the ecological Reserve and the WRYM is now the accepted model that is used to integrate Reserve requirements with those of the broad range of water users in a catchment.

6.3.1 Flow Stressor Response (FS-R)

The FS-R is a method which guides the evaluation of the ecological consequences of modified flow regimes, based on the principles of ecological risk analysis (ERA) (Suter, 1993), using an index of flow-related stress. It is currently limited to the quantification of the low-flow requirements of rivers, such that alternative approaches are still required to evaluate the high-flow requirements.

The term “stress” is used to denote the discomfort/damage suffered by the flow-dependent biota as discharges are reduced. Natural flow regimes normally include low flow episodes which cause stress to elements of the biota (equivalent to components of the natural disturbance regime *sensu* Townsend, 1989). Stress is therefore seen as a requirement for the maintenance of the natural dynamic mosaic of species assemblages through space and time, and the severity of stress likely to be caused by any modified flow regime is judged by how much it is increased or decreased from natural levels.

The FS-R method is designed to be used together with holistic methodologies such as the BBM and DRIFT, as a way of consistently capturing specialist knowledge on the relationship between flow, hydraulic habitat, and the responses of instream biota. The relationships can then be directly translated into a stress ‘regime’ (a description of a time series pattern of stress, similar to a flow regime) for any flow regime, in terms of magnitude, frequency and duration - three of the five critical components of flow suggested by Poff *et al.* (1997). The method is independent of the level of biological knowledge available, although (as with other approaches) this will affect the degree of confidence that can be placed in the flow recommendations.

The method is still being tested and improved, and this is a preliminary description of its application for instream biota at low flows. It concentrates on water quantity requirements, but a parallel process is being developed to assess ecological stresses in relation to water quality.

The basis of the method is the application of a generic stress index describing the progressive consequences to the flow-dependent biota of flow reduction. Table 6.1

provides an example of such an index (from 0 - no stress, to 10 - very high stress) where the stressors, flow hydraulics and associated habitat changes are related to biotic responses in terms of abundance, life stages, and persistence. The definitions apply to instream fauna (and, therefore, separate ones have to be defined for other components of the biota, such as riparian vegetation), and are calibrated for organisms that would require flowing water conditions for optimal habitat.

The index in Table 1 reflects instantaneous or short-term biotic responses. Even sensitive rheophiles seem able to persist during short periods of low or even no-flow (e.g. Chutter & Heath, 1993; Tharme & King, 1998), but may disappear in response to prolonged flow reduction. The longer-term temporal dimension is taken into account when the flow-stress relationships are converted to stress time series using a hydrological time series. The characteristics of the stress regime can then be quantified by calculating the frequency and duration of different stress magnitudes. The process for application of the FS-R method is as follows (more details are provided in Appendix J):

The selected sites of the river are surveyed and described in terms of hydraulic habitat (depth, velocity, and wetted perimeter) at a range of discharges

- The generic stress index is applied to each site by specialist ecologists, to develop stress curves for one or more, critical flow-dependent species or groups. The curves describe the relationship between discharge and stress.
- Where more than one stress curve is produced, these may be integrated to produce a single critical curve, based on the highest stress for any species/group at any discharge.
- It may be appropriate to develop separate stress curves for different seasons, because, for instance, the same magnitude discharge may have quite different stress implications during hot and cool seasons. In such a case, the curves should be used separately to produce seasonal stress profiles.
- The specialist hydrologist uses the critical stress curve to convert the natural and any other flow time series (e.g. present day or other selected scenario) to time series of stress.
- The resulting stress time series are analysed in various ways to characterise the stress regime and to describe the magnitude, duration and frequency of stress levels experienced by the target organisms for the flow scenarios. Two possible analyses are stress duration curves and spell analysis for the median stress level.
- The natural stress profile provides a reference against which to assess the relative changes in biotic stress for the various flow scenarios.
- One of the tasks of the specialists is to define stress characteristics that can be considered adequate for different ecological category rivers. One way of achieving this is to generate possible flow regime scenarios for several ecological categories using the Desktop or IFR (daily time step) models. These would be converted to stress time series and evaluated by the ecological specialists. This process would then pass through several iterations until the stress characteristics of the river under the different ecological category conditions are satisfactorily defined.
- This information can then be carried forward to any future assessments where additional flow scenarios (with management constraints and user demands added) can be compared with the ‘calibrated’ stress regime characteristics.

Table 6.1 Flow Stress/Response generic table for low flows

An example of a generic index of stress for flow-dependent instream fauna in terms of stressors (defined as reduction in low flow and altered physical habitat) and responses (defined as changes in the abundance of target species; risk to sensitive life-stages; and altered persistence). WP = Wetted perimeter.

NB 1: The stress index relates to instantaneous, or at least short-term levels of stress. The frequency and duration of stresses is built into the analysis process when the stress indices are applied to flow time series.

NB 2: The 'Site specific discharge' column is filled in in relation to hydraulic conditions at a particular site, the flow in the top row relating to the lowest flow at which there will be no risk to the most sensitive flow-dependent organism/component. Each specialist then identifies the flow above which each target organism/component will be at no risk. This flow equates to a zero stress for that target organism/component. Each specialist then identifies the flows at which each target organism/component will experience the response described. Some highly sensitive organisms may disappear at a stress of 7, while some more tolerant organisms will survive to a stress of 9 or even 10. The objective is therefore to identify a range of flows at which a range of organisms/components will experience an increasing risk of reduction in numbers and disappearance.

Footnotes:

- *For specific sites and target species, one or more of the hydraulic variables may best reflect changes in stress level. This also applies to "physical habitats". Depending on the type of river channel, the habitats may not always match up to the hydraulics in each row. In these cases, the table may need to be modified to suit local conditions.*
- *Depth, velocity and WP are the variables that have been chosen for this example table, since these are the most commonly considered descriptors of hydraulic habitat in environmental flow assessments. As the method is tested, it may be appropriate to include other variables (e.g. Froude number, benthic shear stress etc.).*
- *"Fast" and "deep", and "wide", in this context mean high maximum velocity and maximum depth, and extensive WP, and will be relative to the size and physical structure of the study site. The interpretation will also be in relation to the preferred hydraulic ranges of the target organism(s). The authors have assumed that the structural and resultant hydraulic complexity of most natural river channels ensures that, when there are areas of fast deep flow, there will also be shallow areas of slow or no flow, for instance at the channel edges, and in backwaters (Rowntree & Wadeson, 1996). It can therefore be assumed that habitat remains at suitable flows for most species which do not require (or prefer to avoid) high velocities and depths.*
- *Physical habitat is addressed in terms of quantity and quality. Quantity refers to the proportional representation of different habitat types by area and number of patches, and "in excess" implies that available habitat exceeds population requirements at the time of the study. "Quality" refers to the diversity and hydraulic connectivity of habitat types.*
- *The criteria listed in these three columns should be treated as guidelines, which may vary for different river types. For instance, in semi-arid rivers, many rheophilic species may be euryoecious, and able to survive the disappearance of preferred habitats for extended periods (Davies et al., 1994).*
- *"Rheophilic" is used to denote species which prefer flowing water conditions. "Sensitive rheophilic" is used to denote species which are entirely dependent on flowing water conditions to complete their life-cycle.*
- *"Healthy" indicates that organisms are in preferred conditions throughout the life-cycle.*
- *"Viable" implies that the life-cycle is functional, but conditions may be marginal.*
- *"Persistence" implies at least local presence of the organism(s). Disappearance of populations /species/groups signifies at least emigration from the site, but includes possible local or wider extinction, at temporary or longer-term scales.*

Site specific discharge (m^3s^{-1})	**[1]Stressors**	
	[2,3]Flow-related hydraulics	**[4]Physical habitat**
	Very fast Very deep Very wide WP	*In excess Very high quality*
	Fast Deep Wide WP	*Plentiful High quality*
	Fast Deep Wide WP, slightly reduced	*Critical habitat sufficient Quality slightly reduced*
	Moderate velocity Fairly deep WP slightly/ moderately reduced	*Reduced critical habitat Reduced critical quality*
	Moderate velocity Some deep areas WP moderately reduced	*Critical habitat limited Moderate quality*
	Moderate/slow velocity Few deep areas WP moderately/very reduced	*Critical habitat very reduced Moderate/low quality*
	Moderate/slow velocity No deep areas Narrow WP	*Critical habitat residual Low quality*
	Slow Shallow Narrow WP	*No critical habitat Other habitats moderate quality*
	Slow Trickle Very narrow WP	*Flowing water habitats residual Low quality*
	No flow	*Standing water habitats only Very low quality*
	No surface water	*Only hyporheic refugia*

	[5]Biological responses of target organism(s)		
Stress Index	**Abundance**	**Aquatic Life Stages**	**[8]Persistence**
0	*Very abundant*	*All [7]healthy*	*Yes*
1	*Abundant*	*All healthy*	*Yes*
2	*Slight reduction for [6]sensitive rheophilic spp*	*All healthy in some areas*	*Yes*
3	*Reduction for all [6]rheophilic species*	*All healthy in limited areas*	*Yes*
4	*Further reduction for all rheophilic species*	*All [7]viable in limited areas, critical life-stages of some sensitive rheophilic species at risk*	*Yes*
5	*Limited populations of all rheophilic species*	*Critical life-stages of sensitive rheophilic species at risk or non-viable*	*Yes*
6	*Sensitive rheophilic species rare*	*Critical life-stages of sensitive rheophilic species non-viable, and at risk for some less sensitive species*	*In the short-term*
7	*Most rheophilic species rare*	*All life-stages of sensitive rheophilic species at risk or non-viable*	*Most sensitive rheophilic species disappear*
8	*Remnant populations of some rheophilic species*	*All life-stages of most rheophilic species at risk or non-viable*	*Many rheophilic species disappear*
9	*Mostly pool dwellers*	*All life-stages of most rheophilic species non-viable*	*Most or all rheophilic species disappear*
10	*Only specialists persist*	*Virtually no development*	*Only specialists persist*

6.3.2 Flow Management Plan (FMP)

The Flow Management Plan is a modification from the BBM and devised for use on the Sundays and Fish Rivers (Eastern Cape). The Flow Management Plan (FMP) approach is used specifically where a river has undergone structural changes due to a high degree of management and where the constraints or demands are such that reversal of these conditions is impractical. The major difference between the FMP and the traditional IFR/Reserve approach is that the operational constraints and the operational limits are taken into account when designing the modified flow regime. Rather than Reserve scenarios being supplied, these scenarios will be related to different levels of operational possibilities. The FMP uses the same tools and preparatory work as for the BBM.

The FMP is therefore a scenario based approach rather than a bottom up - BBM - approach.

The F-SR described in 6.3.2 will address the FMP much more efficiently than the original FMP approach as used in the Eastern Cape and on the Vaal River. For example, the upper Vaal River is managed with 'too much' water, i.e. the river is used as a conduit and unseasonally high and regular flows. This could allow species that favour these conditions to become pest species (such as black fly (*Simulium chutterei*)) as they now dominate the communities whereas previously they were controlled by the natural disturbance regime and variable flows, especially the natural low flows during the dry season. The natural stress in the system has therefore been removed, and this will be identified in the F-SR approach. Taking account of the structural changes and the operational constraints in the system, the amount of stress that can, within these constraints, be 'put back' into the system can be defined.

It is therefore recommended that the FMP is used within the F-SR rather than within the BBM. The standard F-SR approach will be used as the basis. Once the natural and present day stress profiles have been generated however, the additional scenarios for evaluation will be defined considering constraints rather than considering different ecological river states (i.e. Reserve scenarios).

6.3.3 Downstream Response to Imposed Flow Transformations (DRIFT)

(An abstract from : A summary of the DRIFT process, Southern Waters' Information Report no 01/00, Cate Brown and Jackie King)

Assumptions and main acitivies

DRIFT (King et al, in press) is essentially a data-management tool, allowing data and knowledge to be used to their best advantage in a structured way. Within DRIFT, component-specific methods are used by each specialist to derive the link between river flow and river conditions (biophysical), or between changing river conditions and social and economic impact (socio-economic).

The central rationale of DRIFT is that different aspects of the flow regime of a river elicit different responses from the riverine ecosystem (Table 6.2). Thus removal of part or all of a particular element of the flow regime will affect the riverine ecosystem differently than will removal of some other element. Furthermore:

- It is possible to identify and isolate these elements of the flow regime from the historical hydrological record.
- It is possible to describe the probably biophysical consequences of partial or whole removal or a particular element of the flow regime, in isolation .
- Once these biophysical consequences have been described, it is possible to combine them in various ways to describe the overall impact on river conditions of a range of potential flow regimes.
- Once the potential changes in river conditions have been described, it is possible to describe their socio-economic implications.

Table 6.2: Different kinds of river flow and their importance to ecosystem functioning

The normal flow flows in the river outside of floods.	Low flows define the basic seasonality of rivers - its dry and wet season, whether it flows all year or dries out for part of it. The different magnitudes of low flow in the dry and wet seasons create more or less wetted habitat and different hydraulic and chemical conditions, which directly influence what the balance of species will be in any season.
Freshes: small floods that occur several times within a year.	Defined here as small pulses of higher flow, freshes are usually of most ecological importance in the dray season. Smaller floods stimulate spawning in fish, flush out poor quality water, mobilise sandy sediments, and contribute to flow variability. They re-set a wide spectrum of conditions in the river, triggering and synchronising activities as varied as upstream migration of fish and germination or riparian seedlings.
Large floods that occur less often than once a year.	Large, scouring floods dictate the form of the channel. They mobilise sediments and deposit silt, nutrients and seeds on floodplains. They inundate backwater areas, and trigger the emergence of flying adults of aquatic insects, which provide food for fish, frogs and birds. They maintain moisture levels in the banks, which support trees and shrubs, inundate floodplains, and scour estuaries thereby maintain the link with the seas.
Flow variability	Variability of flow is essential for a healthy ecosystem. Different conditions are created through each day and season, controlling the balance of species and preventing dominance by pest species.

The DRIFT process involves a number or river-related biophysical and socio-economic activities. At present these are centered in two major workshops, but it is envisaged that much of the work could eventually be done by the specialists prior to much shorter “wrap-up” workshops.

There are eight main activities in DRIFT (post data collection)

- Preparation of the hydrological data and derivation of summary statistics.
- Linkage of the hydrological statistics to cross-sectional river features at a number of representative river sites.
- Reduction of different flow components in a structured series, and description of the biophysical consequences.

- Entry of the consequences into a custom-built database.
- Querying the database to describe the changes in river conditions caused by one or more potential flow regimes (scenarios).
- Identification of the social impacts of each scenario.
- Calculation of the economic cost of compensation and mitigation for each scenario.
- Calculation of the impact on system yield for each scenario.

Disciplines represented in DRIFT

The disciplines represented vary depending on the requirements of the particular project. In general, the biophysical specialist team will consist of representatives of the following disciplines:
Hydrology, hydraulics and physical habitat, water quality, geomorphology/sedimentology, botany, macroinvertebrate ecology, fish.

Specialist in aquatic parasites, algae, aquatic and semi-aquatic mammals and birds, and herpetofauna may also be included on the biophysical team, depending on the specific requirements of the IFR.

Similarly the composition of the socio-economic team is project-specific, and may include specialists in sociology, anthropology, public health, animal health, resource economics, scheme economics and public participation.